N64 11814

CODE-1

(NASA TMX-51275) OTS:

4/p.

NOTES OF THE COSTS OF THE

UNITED STATES SPACE PROGRAM

By

Addison M. Rothrock [1962] 0 refs

cr incl #

Presented At A Joint Meeting of

The Royal Aeronautical Society
and the
British Interplanetary Society,

London, England
February 13, 1962

OTS PRICE

XEROX $ 4.60 ph

MICROFILM $ 1.43 mf.

NOTES OF THE COSTS OF THE
UNITED STATES SPACE PROGRAM

By

Addison M. Rothrock*

INTRODUCTION

The purpose of this paper is to discuss certain aspects of the costs of the United States Space Program. Attention will be concentrated on the work of the National Aeronautics and Space Administration (NASA). The United States Aeronautics and Space Act of 1958 charges the NASA with the responsibility of "exercising control over aeronautical and space activities sponsored by the United States, except that activities peculiar to or primarily associated with---defense of the United States---shall be the responsibility of---the Department of Defense."

Based on the Space Act and the various policy documents issued by the Government, the major responsibilities of NASA can be summarized as:

1. The development of launch vehicles and spacecraft, and the necessary ground support systems, for manned and unmanned space flight.

2. The exploration of space with these manned and unmanned spacecraft.

3. The application (with appropriate international cooperation) of the results of this space exploration to the general welfare of mankind.

* Associate Director, Office of Plans and Program Evaluation, National Aeronautics and Space Administration, Washington 25, D. C.

cP

Of the total United States expenditures in space, about two-thirds are for the NASA program. Most of the remainder is under the jurisdiction of the Department of Defense, with sizeable programs also conducted by the Atomic Energy Commission (jointly with NASA for the development of spacecraft nuclear propulsion and nuclear power generating systems) and by the Department of Commerce in connection with the operation of meteorological spacecraft systems. There are various other corollary programs.

The space flight systems that are used in the conduct of the space programs consist of:

1. Spacecraft payload

2. Spacecraft

3. Launch vehicle

4. Ground based launch facilities

5. Ground based spacecraft tracking and communication systems

The spacecraft payload consists of the instruments or other devices carried aboard the spacecraft to perform the functions for which the flight is being made.

Each part of this space flight system must be developed, the hardware fabricated and placed in operation, and then maintained over a given useful life. The useful life may be measured in minutes (as in the case of a current launch vehicle) or in years (as in the case of the spacecraft tracking system). In addition, continuous research must be conducted to improve the different parts of the system so that activities in space can be extended and so that the operations will become more efficient.

In this discussion time will not permit more than a limited look at certain phases of the costs of space flight operations. The cost break-downs presented will follow those used by an operating organization and the headings will not necessarily follow those that have just been given. Nevertheless they should continually be kept in mind as the essential parts of a space flight system.

OVERALL PROGRAM COSTS

The NASA Space Program can be divided into five parts:

1. Conduct of scientific investigations in Space (Space Sciences)

2. Development of Applications Spacecraft (in meteorology, communications, navigation, etc.)

3. Development and operation of Manned Space Flight Systems.

4. Construction and operation of ground systems for spacecraft launching and for spacecraft tracking, command, and information transmission (Tracking and Data Acquisition).

5. Conduct of flight vehicle research and technology

To conduct this program NASA operates nine major stations:

NASA Headquarters, Washington, D. C.
Langley Research Center, Langley Field, Virginia
Ames Research Center, Moffett Field, California
Lewis Research Center, Cleveland, Ohio
Flight Research Center, Edwards Air Force Base, Cal.
Goddard Space Flight Center, Beltsville, Maryland
Marshall Space Flight Center, Huntsville, Alabama
Manned Space Flight Center, Houston, Texas
Jet Propulsion Laboratory, Pasadena, California

The approximate number of persons employed at these stations and the other NASA establishments is, by calendar year:

1961	1962	1963
20,000	25,000	30,000*

All establishments with the exception of the Jet Propulsion Laboratory are staffed by Civil Service personnel. The Jet Propulsion Laboratory employing about 3000 people is operated under contract by the California Institute of Technology.

About 15 percent of the NASA program is currently conducted in-house, mostly in the field of flight vehicle research and technology. However sufficient work is conducted in the other four fields to insure in-house competence in them. The remaining 85 percent of the NASA program is conducted by industries, universities and non-profit institutions under contract or grants.

The NASA budgets for fiscal years 1961, 1962, and 1963 are shown in Table I.** In this division,

---

* Estimated
**The budget break-down in this and in the subsequent Tables do not necessarily agree with the official NASA budget documents. The sums do agree.

costs of the spacecraft launching ground systems are divided among Space Sciences, Applications Spacecraft, and Manned Space Flight. At the 1963 level it is estimated that the expenditure will be about $20,000 per year for each of the some 20,000 persons assigned to the in-house part of the program and about $350,000 per year for each of the some 10,000 persons assigned to monitor the contract and grants program.

Table I shows that Space Sciences and Applications Programs will a little more than double in the three year period. The Manned Space Flight Program will increase sixfold, and the Tracking and Data Reception and Vehicle Research and Technology Programs about threefold. Overall, the data reflect the increased importance placed on the space program by the Government of the United States.

There is considerable choice that can be made in the amount of money spent in the fields of Space Sciences and Applications Spacecraft and, as a result, in the amounts spent in that part of Tracking and Data Acquisition and Vehicle Research and Technology that support these programs. With Manned Space Flight because of the magnitude of the effort required and probably more importantly because of the international aspects of manned space flight there is not so much choice. The President referred to this in his May 25, 1961 Special Message to the Congress when he stated: "If we were to go only half way, or reduce our sights in the face of difficulty, it would be better not to go at all."

THE SPACE SCIENCE PROGRAM

From this very brief picture of the overall costs of the NASA program the Space Sciences Program will be examined in more detail. The program can be divided into five parts as shown in Table II. The titles listed are those currently used in the official NASA budget documents. Sounding Rockets are those operations in which the spacecraft, that is the rocket payload, is flown in a more or less vertical trajectory. The time in space is measured in minutes. The designation Scientific Satellites currently refers to those spacecraft placed in an earth orbit and used for scientific investigations. Lunar and Planetary Exploration consists of operations with those spacecraft which are launched from the earth into a lunar orbit or landing, into an earth orbit that passes sufficiently close to the moon for lunar observations, or spacecraft which are launched into a solar orbit that passes close to a planet. In later programs planetary orbits and landings will be attempted. These lunar and planetary spacecraft operations are directed toward the exploration of the moon and planets but the spacecraft also carry instruments for measuring various cosmological and solar phenomenon.

The Launch Vehicle Development costs in Table II cover the development of the launch vehicle to the point where it is considered reasonably reliable. Beyond this point the cost of the launch vehicle is included in the appropriate part of the Science Program. The definition of "reasonably reliable" is arbitrary and generally covers the cost through about ten launchings. It also covers certain product improvement costs. It is interesting to note that the costs on Scout and Centaur do not show much variation in the three year period and are roughly proportional to the overall size of the vehicles. The development costs for Delta indicate this is now a reliable vehicle. Its record of operation substantiates this statement. Construction of facilities represent for the most part those ground installations at the Goddard Space Flight Center and at the Jet Propulsion

Laboratory used in conjunction with the development of the spacecraft and spacecraft payload and the laboratories, shops, and offices for the personnel (currently 1700 at Goddard and 3000 at the Jet Propulsion Laboratory).

Returning to the first four items in Table II, it is noted that the Sounding Rocket Program is increasing at a relatively low rate. The program consists of about 100 shots a year. This program can be maintained at a choice of levels down to a few shots a year. The threefold increase in the Scientific Satellite and Lunar and Planetary Programs over the three year period represents an increase in the size and operational flexibility of the spacecraft rather than an increase in the number of launchings. The larger spacecraft carry either a greater number of experiments or permit a larger range of measurements to be made with a single experiment. This trend toward larger spacecraft with greater operationally flexibility has been quite marked as the programs have increased in scope and magnitude.

By choosing smaller spacecraft and by conducting the operations in an earth orbit rather than including solar orbits a program in space sciences can be conducted at an appreciably lower cost than that presented in Table II. Using conventional liquid propellants and present state-of-the-art design, a three stage launch vehicle of 30 times the mass of the spacecraft is suitable to launch the spacecraft into a 300 mile earth orbit. To launch the spacecraft into a solar orbit trajectory a launch vehicle of about four times this size - 120 times the spacecraft mass - is required. The relation of launch vehicle to operating costs will be discussed in more detail later.

COSTS OF A PARTICULAR PROGRAM

To further examine the costs of the NASA program and to illustrate the points just made the annual expenditures for the scientific satellite program over the three year period are further itemized in Table III. The International Satellite Programs UK #1 and UK #2 are conducted jointly by the United Kingdom and the United States with the United Kingdom supplying the spacecraft payload, that is the experimental instrumentation. The monies shown are for the United States part of the program. The Topside Sounder is conducted jointly by Canada (supplying the spacecraft payload and spacecraft) and the United States, the costs shown being the United States contribution, that is the launch vehicle and launching cost. The supporting research and technology program in this table has to do with the development of the spacecraft and the spacecraft payload, largely the latter. This work is conducted both in-house and under contract. The data in Table III assist in indicating the manner in which a program at various funding levels might be conducted.

For a more detailed account of costs, Table IV shows a breakdown for the two energetic particles satellites. The first of these, the S-3 Explorer XII, was successfully launched August 16, 1961 and transmitted data back to earth for 112 days. Appendix A discusses the results procured from the various experiments conducted during the flight. The second energetic particle spacecraft is scheduled for launching later this year. The approximate cost of each of the two flights is $7,200,000 and $4,800,000 respectively. The total for the two flights can be divided as follows:

Part of Program	Fraction of Cost
Launch vehicle	.40
Spacecraft	.20
Experimental equipment (spacecraft payload)	.15
In-house support	.25
	1.00

The in-house support is largely that work conducted at the Goddard Space Flight Center by the Goddard staff in support of the program. The costs of the program do not include the analysis of the data and preparation of reports by the various experimenters listed in Appendix A.

FACTORS AFFECTING LAUNCH VEHICLE COST

The relative cost of the launch vehicle will decrease as the spacecraft are provided with more versatile performance through the incorporation of systems for stabilization, attitude control, power generation, propulsion and so forth. For instance NASA programs for the Orbiting Solar Observatory and for the Nimbus Meteorological Spacecraft show estimated launch vehicle costs at 25 percent of the total operation. In addition to the proportionally higher cost of the spacecraft, the launch vehicles are becoming more "efficient" in relation to the ratio of spacecraft mass to launch vehicle mass.

Table V summarizes the performance of the launch vehicles used or scheduled for use in the Space Science Program. All are operational except the Centaur. The decrease in the ratio of payload to launch vehicle weight as the launch vehicle sizes are increased results partly from a scale effect, but more to improvements in state-of-the-art and to improved stage matching as discussed in the next several paragraphs.

The ratio of the spacecraft (launch vehicle payload) mass to the launch vehicle mass is proportional to:

1. The specific impulse of the launch vehicle propellants.

2. That part of the total mass of each launch vehicle stage that is propellant (stage propellant fraction).

3. The ratio of the mass of each stage to that of the subsequent stage.

The interrelation of these three variables can be examined with sufficient accuracy with two simplifying assumptions. These are (1) the ratio of the mass of each stage to that of the subsequent stage is the same throughout the system, and (2) all stages use the same propellants and have the same stage propellant fraction.

For such a system, it is reasonable to use the relation:

$$\frac{PL}{M_n} = \frac{1}{Y-1} \quad \text{(see Appendix B)}$$

in which PL is launch vehicle payload (spacecraft mass)

- n is number of launch vehicle stages
- M_n is mass of last stage of launch vehicle
- Y is ratio of mass of each stage to the mass of the subsequent stage

From this relationship

$$\frac{PL}{\Sigma_{n=n}^{n=1} M} = \frac{1}{Y-1} \times \frac{1}{Y^n + Y^{n-1} + \text{---} Y^{n-n}}$$

The other major factor of interest is the injected payload velocity. It is given by the conventional equation

$$\frac{\text{Total } \Delta V}{V_j} = n \frac{\Delta V_{st}}{V_j} = n \ln \frac{M_n + PL}{XM_n + PL}$$

$$= n \ln \frac{Y}{X(Y-1)+1}$$

in which

Total ΔV is spacecraft injection velocity (payload injection velocity)
ΔV_{st} is velocity increase per stage
V_j is launch vehicle propellant (exhaust) velocity
X is ratio of stage mass at burnout to stage mass at ignition (stage propellant fraction = 1 -X)

The value of $\frac{\Delta V_{st}}{V_j}$ is dependent on the value of X as shown in Figure 1. In general the value should not be less than 1.0 or greater than that giving a ratio of payload to stage mass of 0.1, that is 1.5, 1.7 and 2.0 for stage propellant fractions of 0.85, 0.90, and 0.95 respectively. In general for current state-of-the-art solid propellant rocket the stages have stage propellant fractions of 0.82 to 0.90 and for liquid rockets of the order of 0.90.

Figure 2 shows the results for 1 to 4 stage launch vehicles for the stage propellant fractions previously given. The points labeled according to specific impulse in seconds, if read from right to left, represent reasonably well the progress that has been and is being made in launch vehicles (compare with Table V). These points represent a launch into a 300 nautical mile orbit with a total injection velocity, including losses, of 30,000 feet a second. The losses, about 4000 feet a second, include decreased specific impulse at the lower altitudes of the flight path and gravity and friction losses. The improvement in payload ratio indicated is from 0.004 to 0.070. The latter point represents an oxygen-hydrogen two stage rocket with $\frac{\Delta V_{st}}{V_j}$ somewhat greater than 1.0 - say 1.2. Through advances of this sort cost per pound of launching the spacecraft can be expected to decrease to a third the current values.

As mentioned previously current higher costs result from early state-of-the-art techniques and from inadequate staging ratios. The effects of inadequate staging are illustrated in Figure 3. In the figure the solid curve represent optimum design for a two stage vehicle estimated according to Appendix B. The broken curves show off-design performance from the optimums as indicated. A total $\frac{\Delta V}{V_j}$ of 3.0 represents injection into orbit with a specific impulse of 310 sec. or injection into earth escape with 425 sec. and 4.0 represents injection into earth escape with 310 sec. (in each case including losses). The curve shows the manner in which a two stage vehicle designed for injection into a 300 n. mi. earth orbit (stage ratio 6.0, specific impulse 310 sec.) but used to inject into escape becomes less "efficient" than the optimum design for escape by a factor of 3:1 and in fact becomes marginal. The curve also shows that a launch vehicle designed for escape injection has an "efficiency" loss of 1.3:1 if used for the earth orbiting injection. Launch vehicles constructed through adaptations of rocket motors built for other purposes are apt to result in inadequately staged combinations.

Additional launch vehicle information is shown in Figure 4 in which curves are shown for $\Delta V_{st}/V_j$ of 1.0 and 1.5. The curves illustrate the manner in which the number of stages to earth orbit or to escape can be decreased by improvements in propellant specific impulse and in stage propellant fraction.* Adequate information on the relation of the number of launch vehicle stages to operational reliability and the factors controlling this number is not too satisfactory, but the information existing should be considered very carefully by any group starting development of launch vehicles.

All launch vehicles used to date by the United States employ propulsion systems originally developed for other purposes. This has inevitably resulted in mismatching as far as stage ratios are concerned and has resulted in certain cases in performance approaching marginal conditions. This situation leads to higher costs per pound of spacecraft

---

* It is noted that the point (2.0, 0.097 for a 2-stage vehicle with $\frac{\Delta V_{st}}{V_j} = 1.0$ also represents the payload to launch vehicle mass ratio for a single stage with X = 0.95 and a 465 sec. specific impulse.

launched. However, it must be remembered that this multiple use of propulsion systems leads also to increased reliability which can more than justify this otherwise unsatisfactory compromise.

TRACKING AND DATA ACQUISITION

The purpose of the NASA Spacecraft Tracking and Data Acquisition System is to provide the following services for all spacecraft in the NASA flight program:

1. Determination of spacecraft orbits and trajectories.

2. Transmission of commands to the spacecraft.

3. Reception of information transmitted from the spacecraft.

4. Processing of the received information (data).

The Tracking and Data Acquisition System is divided into three categories:

1. Satellite network for spacecraft travelling in near-earth orbits.

2. Deep space network for spacecraft travelling at or to great distances from the earth.

3. Manned spacecraft.

Since spacecraft travelling near the earth pass rapidly across the ground station field of view many such stations are needed, Figure 5. The stations used with communications and meteorological spacecraft must have the ability to handle large volumes of radio data. Stations for lunar and planetary distances require powerful antennas and sensitive receivers, but contact times between spacecraft and ground station are increased because the direction of travel is more along the line of sight than across it. Manned space flight requires continuous reception with a high degree of reliability.

The NASA budget for procurement, operation, and maintenance of the required world wide spacecraft and data acquisition system is shown in Table VI.

Of the Systems Development about 2/3 is spent to improve existing systems and 1/3 to develop new systems.

The Network Operations are divided into five major headings, Table VII.

As a rough estimate, the manned flight network system accounts for about half of the total costs.

An important and encouraging fact concerning these tracking and data acquisition system is that a world wide system through appropriate timing and coordination can meet the needs of many programs conducted by many nations or by several groups of nations. It is the policy of the United States to supply such cooperation in the use of its tracking and data acquisition networks.

LAUNCH FACILITIES

The cost of launch facility installations depends much on the location of the facilities and the number of facilities at each location. These will not be discussed here other than to list the approximate costs in Table VIII. Necessary adjuncts to the facilities, such as service buildings, etc., will add about ten percent to these figures.

FLIGHT VEHICLE RESEARCH AND TECHNOLOGY

The NASA program for flight vehicle research and technology is oriented towards nuclear energy applications as shown in Table IX. The large increase in Construction of facilities in 1963 is for the most part modernization of the in-house capabilities of the Research Centers to meet the Space needs. Except for this increase about half the monies are for research and technology in the application of nuclear energy to spacecraft propulsion and power generation. The sums for aircraft and missiles apply only indirectly to the space effort.

CONCLUDING REMARKS

This very brief summary of space program costs has given a picture of the manner in which the costs of the NASA program are divided into the different categories and programs. It has also been the intent of this discussion to give a certain feel for the manner in which a space program can be tailored to fit different needs. One fact is particularly evident in all discussions of space flight costs, namely, that the magnitude of the efforts required for adequate exploration and use of Space requires that international cooperation reach a level that has not previously existed in man's conquest for knowledge.

ACKNOWLEDGMENT

The Author wishes to express his appreciation to John Tartaglino of the NASA Headquarters Staff for his assistance in preparing this paper.

TABLE I

NASA ANNUAL BUDGETS
in $1,000,000

PROGRAM	FY[1] 1961	FY 1962	FY 1963[2]
Space Sciences	260	395	570
Applications Spacecraft	58	107	140
Manned Space Flight	423	806	2507
Tracking and Data Reception	73	125	213
Vehicle Research and Technology	152	239	513
TOTAL	966	1672	3943

[1] Fiscal Year
[2] As recommended by the President, includes 1962 Supplemental

TABLE II

SPACE SCIENCES ANNUAL BUDGETS
in $1,000,000

	FY 1961	FY 1962	FY 1963
Science Programs			
Sounding Rockets	12.3	14.3	19.2
Scientific Satellites	54.4	117.6	175.2
Lunar and Planetary Exploration	91.0	170.0	273.6
Total Programs	157.7	301.9	468.0
Launch Vehicle Development			
Scout	9.7	8.2	8.9
Delta	10.5	2.9	.3
Centaur	64.7	65.8	75.7
Total Launch Vehicle Development	84.9	76.9	84.9
Total	242.6	378.8	552.9
Construction of Facilities	17.0	17.7	16.6
TOTAL	259.6	396.5	569.5

TABLE III

SCIENTIFIC SATELLITES ANNUAL BUDGETS in $1,000,000

	FY 1961	FY 1962	FY 1963
Supporting Research and Technology	13.0	27.0	33.7
Flight Programs			
Orbital Geophysics Observatory	5.4	28.2	58.6
Orbital Astronomical Observatory	7.5	32.4	45.7
Orbital Solar Observatory #1	1.1	1.9	0.9
Orbital Solar Observatory #2	2.8	2.3	2.9
Advanced Orbital Solar Observatory		0.3	11.7
Topside Sounder	4.8	12.0	0.9
Ionosphere Monitor			3.0
Geoprobes			4.4
Energetic Particles Satellite	3.1	2.1	0.3
Atmospheric Structure Satellite	3.5	1.8	0.6
Biological Experiment	0.2	2.1	3.6
International Satellite UK #1	2.7	3.6	0.3
International Satellite UK #2	.1	1.7	5.2
Other International Satellites			3.4
Ionosphere Direct Measurement Satellite	2.0	0.1	
Micrometeroid Satellite	2.9	0.5	
Gamma Ray Astronomy Satellite	1.6		
Electron Density Profile Probe	1.6	1.5	
Ionosphere Beacon Satellite	2.1		
TOTAL	54.4	117.6	175.2

TABLE IV

COSTS OF ENERGETIC PARTICLE SCIENTIFIC SATELLITE FLIGHTS
in $1,000,000
(Flights S-3 (Explorer XII) and S-3a)

	FY 59	FY 60	FY 61	FY 62	FY 63	Total
Payload (Instrumentation), Spacecraft and Launch Vehicles						
Design and Development of Particle Detector Instrument		.1	.3	.3	.2	.9
Development of Optical Aspect and Power Systems		.1	.3	.3		.7
Basic Spacecraft Structure, Design, Development and Test	.2	.6	.2	.2		1.2
Fabrication, Spacecraft Integration			.7	.3		1.0
Launch Vehicle (2 ea. Thor-Delta)	—	5.0	—	—	—	5.0
Totals	.2	5.8	1.5	1.1	.2	8.8
In-house Support						
Project Management			.1	.1		.2
Business Management			.1	.1		.2
Spacecraft and Sub-systems			.2	.1		.3
Experiments			.1	.1		.2
Test and Evaluation		.4	.6			1.0
Tracking and Data Systems		.1	.4	.5	.1	1.1
Launch Operations	—	—	.1	.1	—	.2
Totals		.5	1.6	1.0	.1	3.2
TOTAL	.2	6.3	3.1	2.1	.3	12.0

TABLE V

SUMMARY OF SCIENTIFIC SATELLITE LAUNCH VEHICLES

		PAYLOAD			
	Nominal	300 n.mi. Orbit		Escape	
Launch Vehicle	Weight, Lbs.	Lbs.	% Launch Vehicle Mass	Lbs.	% Launch Vehicle Mass
Scout	37,000	150	0.4		
Delta	110,000	500	0.5	60	0.05
Thor-Agena	120,000	1600	1.3		
Atlas-Agena	275,000	5000	1.8	750	0.3
Centaur	300,000	8500	2.8	2300	0.8

TABLE VI

TRACKING AND DATA ACQUISITION ANNUAL BUDGETS
in $1,000,000

	FY 1961	FY 1962	FY 1963
Systems Development	11.5	13.0	16.0
Network Operations	24.1	55.4	67.8
Maintenance and Expansion	8.7	26.4	74.6
Construction of Facilities	29.0	31.0	55.0
TOTAL	73.3	125.8	213.4

TABLE VIII

APPROXIMATE COST OF LAUNCH FACILITIES
in $1,000,000

Launch Vehicle	Launch Facility Cost
Scout	6.0
Delta	8.0
Thor-Agena	10.0
Atlas-Agena	30.0

TABLE VII

NETWORK OPERATIONS ANNUAL BUDGETS
in $1,000,000

	FY 1961	FY 1962	FY 1963
Earth Satellite Network	9.7	11.4	17.8
Deep Space Network	4.2	7.0	9.3
Manned Space Flight Network	0.3	22.7	24.0
Network Communications	6.9	12.3	13.2
Data Processing	3.0	2.0	3.5
TOTAL	24.1	55.4	67.8

TABLE IX

NASA BUDGETS FOR VEHICLE RESEARCH AND TECHNOLOGY in $1,000,000

	FY 1961	FY 1962	FY 1963
Spacecraft	27.1	37.1	54.1
Launch Vehicle Technology	13.9	23.1	31.7
Launch Operations Development	0.1	1.8	21.5
Nuclear Thermal Propulsion	25.1	50.2	123.0
Nuclear Electric Propulsion	7.1	17.6	30.5
Spacecraft Power Generation	8.9	14.6	20.2
Chemical Propulsion	11.9	33.2	65.0
Aircraft and Missiles	37.9	41.5	52.6
Construction of Facilities	20.0	20.1	114.0
TOTAL	152.0	239.2	512.6

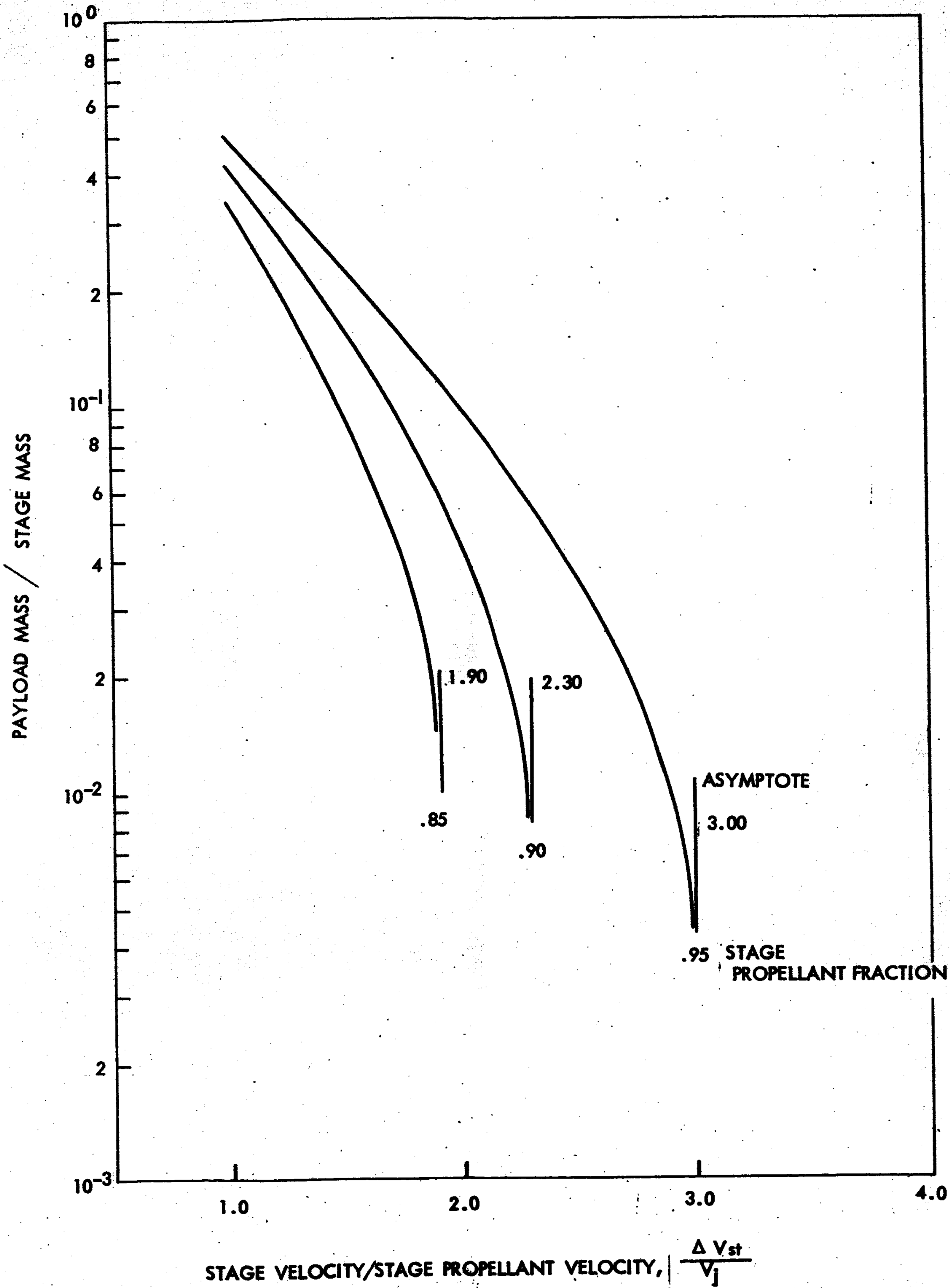


FIGURE I. RELATION OF STAGE PAYLOAD TO RATIO OF STAGE VELOCITY TO PROPELLANT VELOCITY

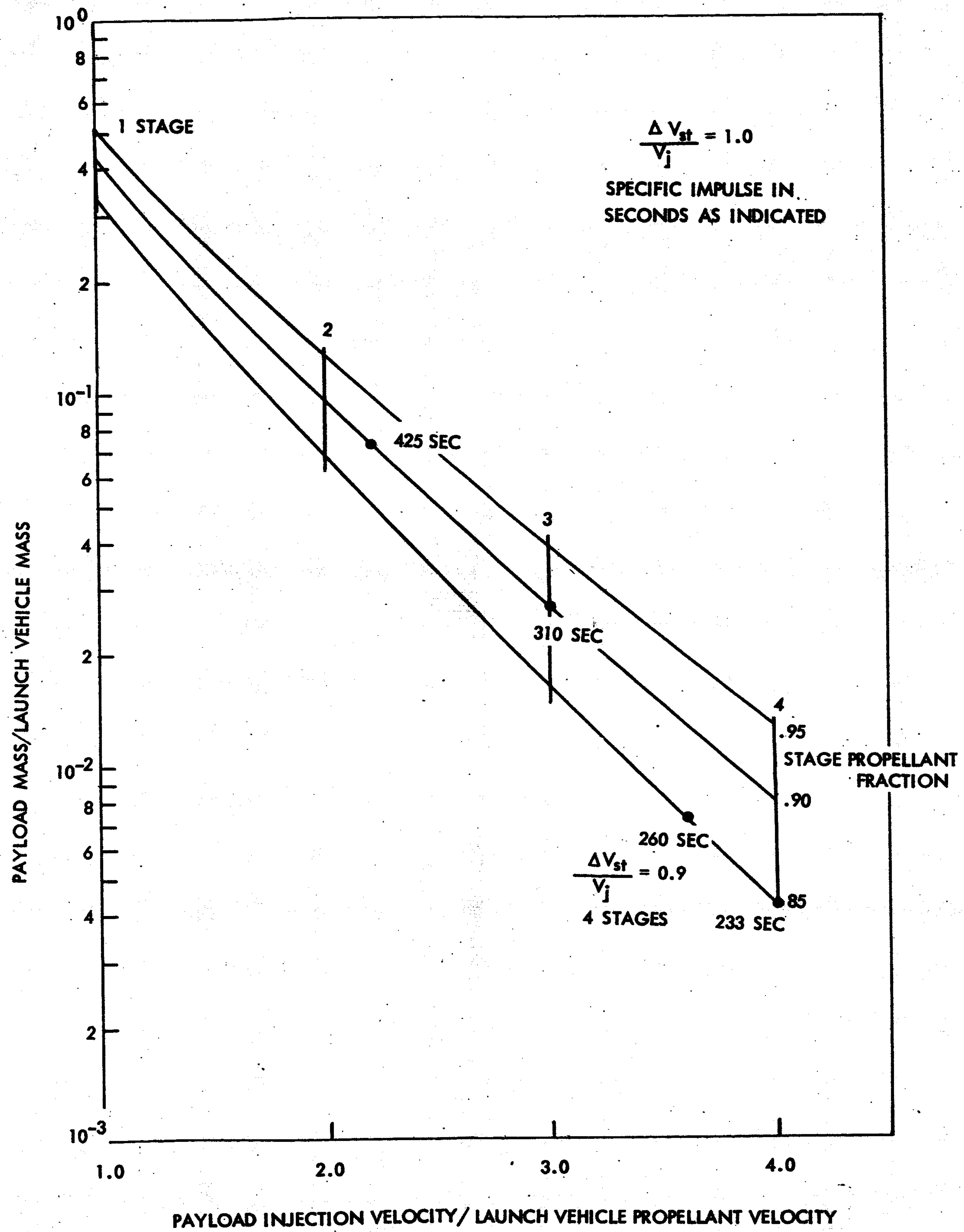


FIGURE 2. RELATION OF PAYLOAD MASS TO PAYLOAD INJECTION VELOCITY FOR DIFFERENT LAUNCH VEHICLE STAGE PROPELLANT FRACTIONS

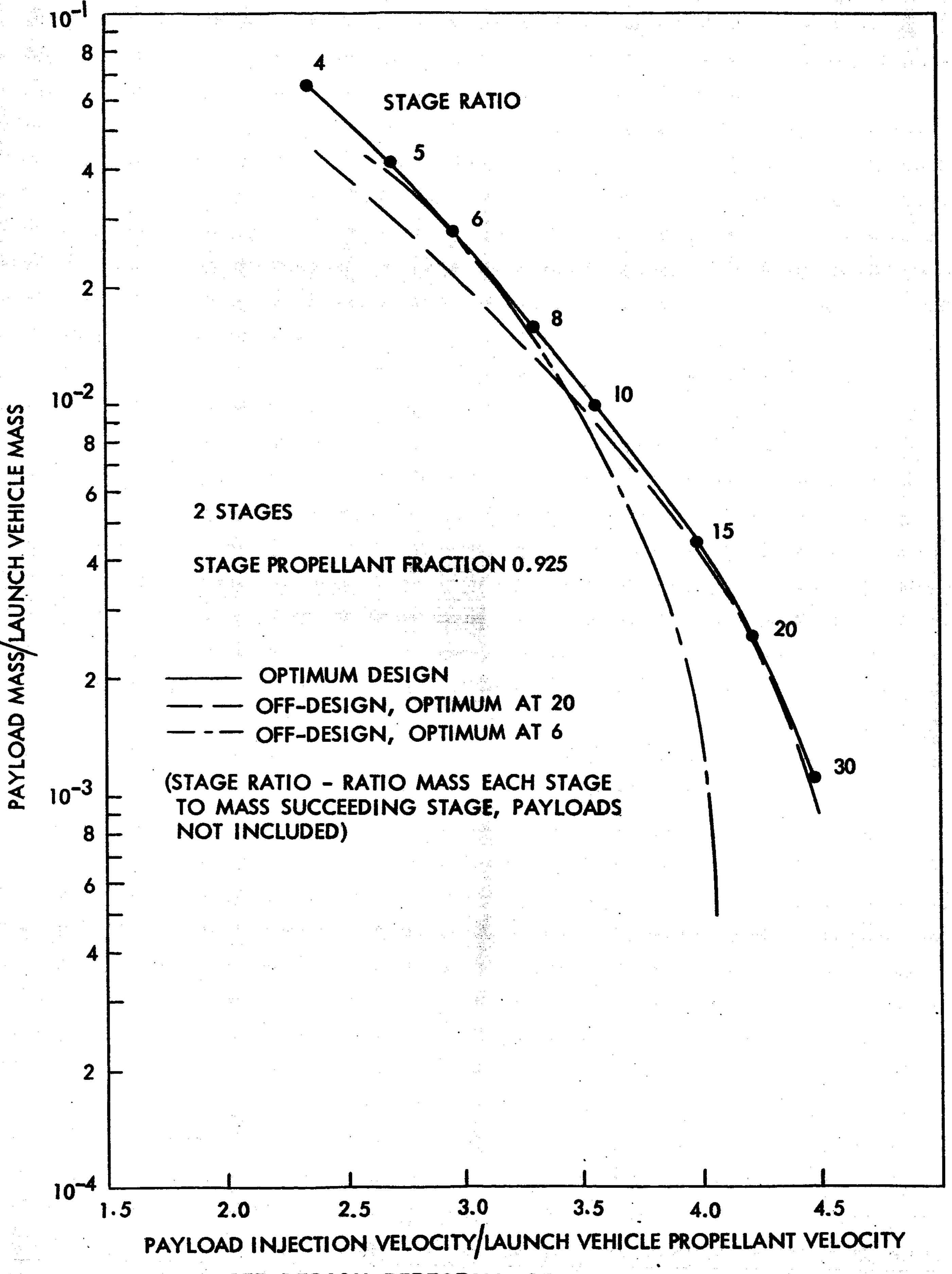


FIGURE 3 OFF-DESIGN PERFORMANCE

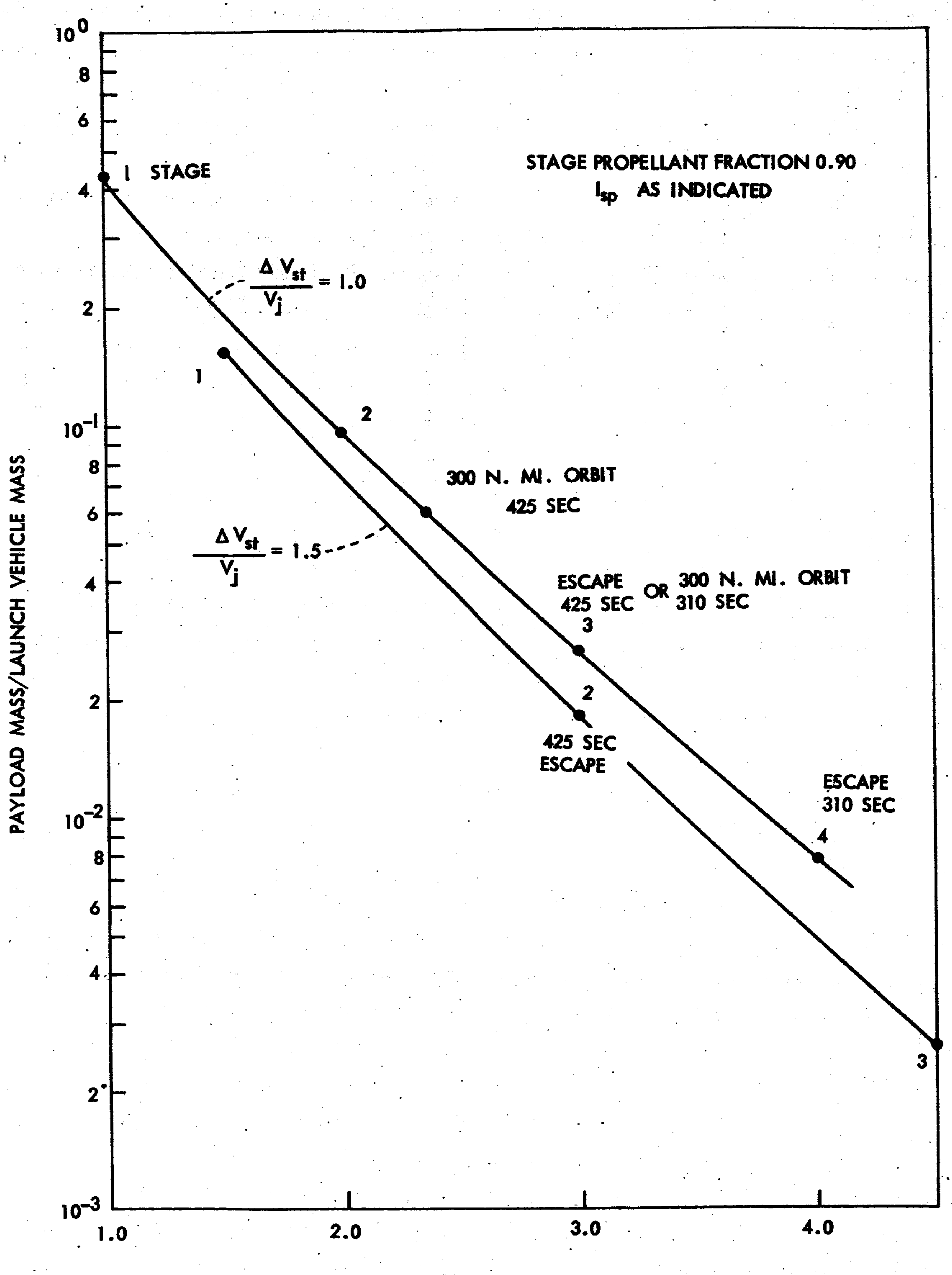


FIGURE 4. RELATION OF PAYLOAD MASS TO PAYLOAD INJECTION VELOCITY FOR DIFFERENT VALUES OF $\frac{\Delta V_{st}}{V_j}$

Figure 5

EARTH SATELLITE INSTRUMENTATION

STATION LOCATIONS

COLLEGE, ALASKA	ANTOFAGASTA, CHILE	EAST GRAND FORKS, MINNESOTA
FT. MYERS, FLORIDA	WINKFIELD, ENGLAND	BLOSSOM POINT, MARYLAND
QUITO, ECUADOR	ROSMAN, N. CAROLINA	ST. JOHNS, NEWFOUNDLAND
LIMA, PERU	GOLDSTONE, CALIFORNIA	JOHANNESBURG, REPUBLIC OF SOUTH AFRICA
SANTIAGO, CHILE	WOOMERA, AUSTRALIA	

T 62-82

APPENDIX A

PRELIMINARY RESULTS FROM EXPLORER XII AS OF JANUARY 19, 1962

Significant scientific results on the nature of energetic particles and the earth's magnetic field have been gained from a preliminary look at data transmitted back to Earth by the S-3 spacecraft, or Explorer XII Energetic Particles Satellite.

The spacecraft was launched August 15, 1961 from Cape Canaveral, Florida into a highly elliptical orbit ranging from a distance of 182 statute miles to 48,000 statute miles. In its 112 days of transmission life it orbited the earth each 26.5 hours. More than 80 percent of its transmission data was stored on magnetic tape; it sent back to earth more data than all previously launched earth satellites. It ceased transmitting on December 6. Cause of the failure is still under investigation.

Experiments carried on board included:

Ames Research Center of NASA: Proton analyzer experiment by Dr. Michel Bader.

University of New Hampshire: Magnetometer experiment by Dr. Laurence Cahill.

State University of Iowa: Trapped radiation experiment by Dr. James A. Van Allen and Dr. Brian J. O'Brien.

Goddard Space Flight Center, Greenbelt, Md: Dr. Frank B. McDonald, cosmic ray experiment; Mr. Leo Davis, ion electron detector experiment; and Gerald W. Longanecker, solar cell experiment.

The project was under the overall management of Goddard Space Flight Center.

NASA said its study of the data has shown that all experiments worked as designed without trouble, and the spacecraft represents one of the most successful flown to date because it was able to measure simultaneously particle populations and their relations with the geomagnetic field.

Significant findings of the spacecraft announced after NASA held a scientific symposium at Goddard Space Flight Center, attended by more than 250 scientists, include:

1. The picture of the magnetosphere (Van Allen Radiation Belts), previously thought as two distinct doughnut-belts surrounding the earth except at the poles

has changed. Explorer XII findings now indicate there is not a distinct inner and outer belt but rather one big trapping region with particles having different characteristics. Physically, it appears:

a. At $1\frac{1}{2}$ earth radii (from the center of the earth) there are high energy protons in the tens of MEV range.

b. At 3 earth radii there are low energy protons of a fraction of an MEV, and the protons are comparable in intensity to the electrons. These constitute the largest energy density of any energetic particles measured in the outer magnetosphere, having a density running as high as 1/10 of the earth's magnetic field density. Maximum intensity exceeded 10^8 protons per cm^2/second. Average energy is about 400 KEV to less than 100 KEV depending on position in the magnetosphere.

c. At 4 earth radii (the older concept of the outer belt) the penetrating components are protons of 20 MEV and/or electrons of 2 MEV. Most likely the electrons are in the majority.

d. At 6 earth radii and out to the outer edge of the magnetosphere (which varies from day to day but is about 8 to 12 earth radii) there are soft electrons in the tens of KEV.

Past satellite and space probe measurements have been interpreted as showing that the intensity of electrons with energy above 40 KEV in the heart of the outer zone was about 10^{11} particles per cm^2 per second. State University of Iowa experiments showed that the previous interpretations had been based on invalid assumptions about the electron spectrum, and that the intensity is only of the order of 10^8 particles per cm^2 per second, a factor of one thousand lower than the previous estimates. It should be noted that this result does not indicate any decrease in the radiation hazard in this region.

2. A magnetometer furnished by the University of New Hampshire did not show evidence of the ring current previously reported by Pioneer V and Explorer VI at 6 to 7 earth radii during the relatively quiet magnetic period in August. Explorer X did not find evidence of this current either.

Importantly, Explorer XII magnetometers found out that in general its magnetic field measurements agree with those which have been made by earth stations. However, at about 10 earth radii the magnetometer and particle measurement devices found that the geomagnetic field dies out, and from there appears to be a turbulent area about 100 kilometers thick before the interplanetary medium is encountered. Field intensity here is on the order of 60 gammas compared with about 57,000 gammas on the earth's surface.

A cosmic ray experiment by Dr. Frank B. McDonald revealed that there are more solar proton events coming from the sun than previously thought. However, these are small events and apparently represent no problem to man in space. The experiment, for the first time, got a more detailed picture of proton events and provided a continuous time picture of protons leaving the sun and coming to earth. When these values are put into a model, it is felt that a much better picture of the interplanetary medium will be the result.

During September, there were several flares on the sun which generates protons which subsequently reached

Explorer XII. One of these events on September 28 was studied by Explorer XII and Injun I. The satellites saw energetic protons within a few hours after the flare as they travelled with velocities around 10,000 km per second straight from the sun to the earth. The intensity of these protons then died away in about five hours. About two days after the solar flare both satellites saw a sudden increase in the intensity of low energy (about 10 MEV) protons at much the same time that a magnetic storm began on the earth, during which there were bright aurora at low altitudes (this was observed in Washington). It is concluded that the low energy protons travelled slowly from the sun with a magnetic storm cloud, although the exact relation is as yet unknown.

A low-energy proton analyzer by Dr. Bader measured particles from 100 EV to 20 KEV. No such particles were found below 10 earth radii. The instrument also showed that at 10 to 13 earth radii the protons came from random directions, which gave further support that there is a transition region between the magnetosphere region and the interplanetary medium.

Mr. Longanecker's experiment consisted of four banks of cells. One bank was not protected and the others had

3, 20 and 60 mils of glass protective coatings on them respectively. On the first two orbits of the satellite, the power output of the unprotected bank decreased 50 percent. From then until the satellite ceased transmitting, degradation continued until final output was 29 percent of the initial output. Cells with 20 and 60 mil coatings did not degrade. The cells with 3 mils of coating had about 6 percent degradation. Evidence shows that the damage was done by protons in the 150 KEV to 4½ MEV range.

APPENDIX B

NOTES ON OPTIMIZED ROCKETS

For a multistage rocket in which specific impulse and mass ratio of all stages are respectively equal, maximum velocity increase is obtained with equal total stage ratios.

$$\frac{M_{n-1} + M_n + PL}{XM_{n-1} + M_n + PL} = \frac{M_n + PL}{XM_n + PL} = \text{total stage ratio}$$

M mass individual stage at ignition
Subscript n, n-1, etc. stage number
PL mass final payload
X Ratio mass individual stage at burnout to mass individual stage at ignition (stage propellant fraction = 1 -X)

rearranging:

$$X(M_n2 + M_nPL - M_{n-1}PL) = M_n2 + M_nPL - M_{n-1}PL$$

for finite values of X other than one:

$$M_n2 + M_nPL - M_{n-1}\,PL = 0$$

or:

$$\frac{M_{n-1}}{M_n} = \frac{1 + \frac{PL}{M_n}}{PL/M_n}$$

$$\frac{PL}{M_n} = \frac{1}{\frac{M_{n-1}}{M_n} - 1}$$

Definition of terms:

Stage Propellant Fraction = 1 -X

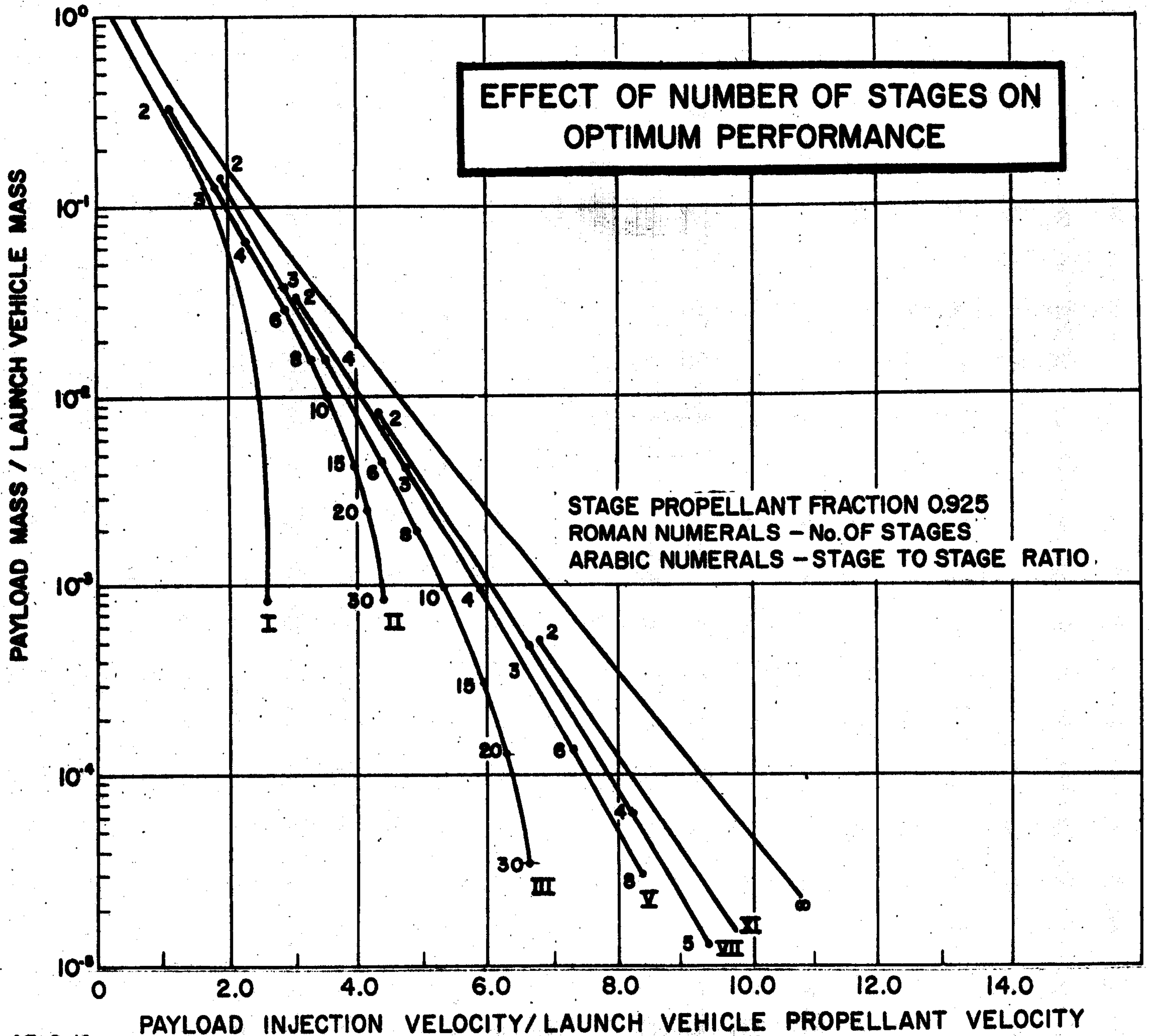
Stage Ratio = $\frac{M_{n-1}}{M_n}$

Vehicle Mass = $M_1 + M_2$ ---- $+ M_{n-1} + M_n$

Total Mass at Launch = $M_1 + M_2$ ---- $M_{n-1} + M_n + PL$

Figures B-1 and B-2 show representative results.

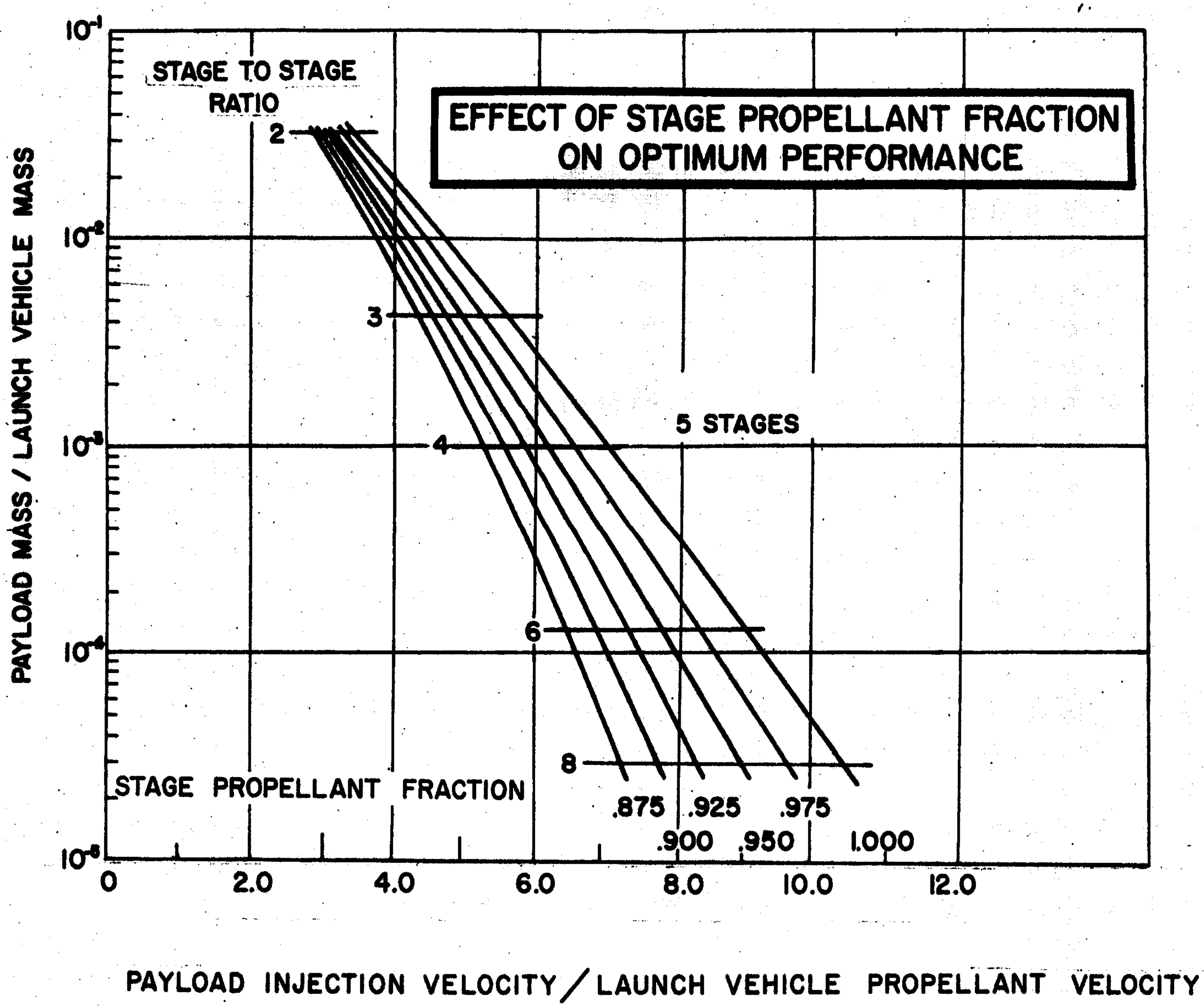
FIGURE B-1



AE-8-19
REV. 2/5/62
REV. 2/21/62

NASA Slide 2764

FIGURE B-2



AE-9-9
REV. 2/21/62

NASA SLIDE 2814